Health Monitoring of Solar PV Distributed Generation System using Soft Computing Approach

Ph D Synopsis

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December - 2016

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Motivation

India is the 2nd most populated country in the world and hence, the need of electricity is also very high. Normally the usual fuels used for the production of energy are unsafe for the environment. The energy sources which are clean and cannot be exhausted are known as renewable sources (solar, wind, hydro, etc.). Utilization of Energy from sun i.e., Solar energy is the one of the preferred vision of India to develop the nation. There are several plans (like solar cities, model cities, green campus, solar technology parks etc) initiated by the government of Indian. Therefore to achieve an efficient, better and reliable generation of solar energy, it is necessary to monitor the solar generation system continuously and analyzed the monitored signals with the help of some latest techniques to identify the conditions of system.

1. Introduction

The energy generation from sun helps to fulfill the energy requirement of the nation. The usual fuels like coal, wood etc have a limited reserve and they pollute the environment, resulting in global warming and green house gas effect. On the other hand, the renewable sources are non-polluting and available in abundance. The renewable sources consist of solar, wind, geothermal, biomass, hydro energy, tidal energy, wave etc. [1]. Therefore, energy from sun may be a good alternative for the future energy requirement [2], because the availability of sun in India is almost whole year except rainy season. Sun has unlimited energy, its radiations produce solar energy through solar generation system. There are lot of research is going on in the area of solar generation to increase its efficiency, reliability, storage etc. Also lots of technologies changes taking place for better productions and planning of solar energy [3]. The environment as well as the earth receives 3.6×10^{24} *Joules* / *year* (radiations in approx. value) [4] while India gains 5×10^{15} *kWh* / *year* solar energy (approx. value). The solar energy received by India in one day is $4-7 kWh/m^2$. Hence, the developing country like India, solar energy generation is one of the best options to meet with the present demand of electricity. When solar power generation using PV panels increases, it is necessary to continuously monitor the health of solar distributed power generation system. The soft computing methods like Fuzzy logic, ANN, GNN [5] may helpful in monitoring.

2. Literature Review

2.1) Status of Renewable Energy in World:

In global market the world will achieve a target of 800 GW installed capacity by 2035 [6] while in 2013, total 135 GW solar photovoltaic were installed in world [7]. The developed country Japan faced problems of tsunami as well as earthquake in 2011 which severely affected the country's power conditions and future policies. Therefore Japan started its initiative towards solar power applications [8].

2.2) Status of Renewable Energy in India:

In India the energy demand raised rapidly during the past years, as energy is needed for the industrialization as well as for many means. The undesirable effects and scarcity of the conventional fuels attracted Government of India to focus its goal on production of energy from renewable energy sources. The statistics of *"India Energy Outlook 2015" (World Energy Outlook special report)* released by "*IEA" (International Energy Agency), "Global Status Report on Renewable 2015"*and *"MNRE" (Ministry of New and Renewable Energy)* are discussed. India secured 5th rank in the total renewable power capacities (excluding hydro) in world in 2014 while china was at 1st position according to *"Global Status Report on Renewable 2015"*. According to *"Global Status Report on Renewable 2015"* in 2014 the world's Solar PV capacity reached 177 GW out of which 0.7 GW is added by India [9].

Table 1 is showing statistics of India's electricity demand and generation for the year 2013 and their projection for 2040 according to the *"India Energy Outlook 2015" (World Energy Outlook special report)* released by "*IEA" (International Energy Agency)*. Till the year 2022 India plans to achieve 175 GW installed renewable capacity (excluding hydro power) [10]

Table 1 Electrical Energy Scenario in India [10]

S. No	Year	Electricity Demand (GWh)	Electricity Generation (TWh)	Installed Power Capacity (GW)	Target of Solar Power Generation Capacity (GW)
1	2013	897	1193	290 (in 2014)	3.7 (in 2014)
2	2040	3300	4100	1075	182

2.3) Strategies of Renewable Energy: Plans and Achievements of Solar Energy

The *"MNRE"* started a number of schemes to produce power from the renewable energy sources like establishment of solar cities (inclusive of green campus, institutional campus, industrial town, town ships, SEZs), and RE (renewable energy) projects etc. In 11th five year plan 60 cities/ towns are selected to develop as solar cities, out of which the "Ministry of new and renewable energy" will support 1-5 cities from each state. For a solar city the requirement of the population must be from 0.50 lakh to 50 lakh with the relaxation to some particular states (like NE states, hilly states, islands and union territories). After the selection and approval of the master plan of the above cities/ towns/ campus etc, these are developed through financial assistance and technical help. The financial assistance under solar city program depends on the population and initiatives as to be taken by council of the city/ city administration and is granted up to Rs 50 lakh per city/town. In continuation of the establishment of solar cities 48 cities are selected for the in-principle approval by the state governments (3 cities from Uttar Pradesh are Agra, Allahabad and Moradabad) and 31 cities are sanctioned which got in-principle approval (cities from Uttar Pradesh are Agra, Allahabad and Moradabad). The sanctioned and released amounts (lakh) to Agra are Rs 48.89 and Rs 38.89 respectively. The Table 2 given below shows the latest report of in-principle approved cities, sanctioned and released amount (in Rs (lakh)) of Uttar Pradesh. Table 3 given below shows the latest report of solar cities which are approved, their master plan status and status of solar city cell for Uttar Pradesh. The Table 4 given below shows financial status of the development program of solar cities [11].

Table 2 The latest report of in-principle approved cities, sanctioned and released amount (both in Rs lakh) of Uttar Pradesh [11]

S.No	State	In-principle Approved cities	Sanctioned Amount (Rs lakh)	Released Amount (Rs lakh)
1	Uttar Pradesh	Agra	48.89	38.89
2		Moradabad	50.00	25.00
3		Allahabad	49.82	2.45

Table 3 The latest report of solar cities which are approved, their master plan status and status of solar city cell for Uttar Pradesh (as on 19/08/2015) [11]

S.No	State	Solar cities which are approved	Master plan status	Whether Solar city cell created
1	Uttar Pradesh	Agra	Prepared	No
2		Moradabad	Prepared	Yes
3		Allahabad	Under preparation	No

Table 4 The financial status of the development program of solar cities [11]

S No	Sector	Sanctioned Amount (Rs lakh)	Released Amount (Rs lakh)
1	50 Cities (for master plan, solar city cells, promotional activities)	2369.15	610.97
	12 Cities (Installation of renewable energy projects)	4281.18	1783.76
3	Green campuses	70	12.85

Besides above 8 Model solar cities, 15 Pilot solar cities, 14 Green campuses (also Dayalbagh Nagar Panchayat) and RE projects in solar cities are also to be established.

The following Figs. 1-3 show the bar charts of the targets and achievements of the renewable energy sources for the financial year 2015-16. The Grid interactive power is shown in Fig.1, The Off grid/capacitive power is shown in Fig. 2, The Capacities of other renewable energy systems is shown in Fig. 3 [11].

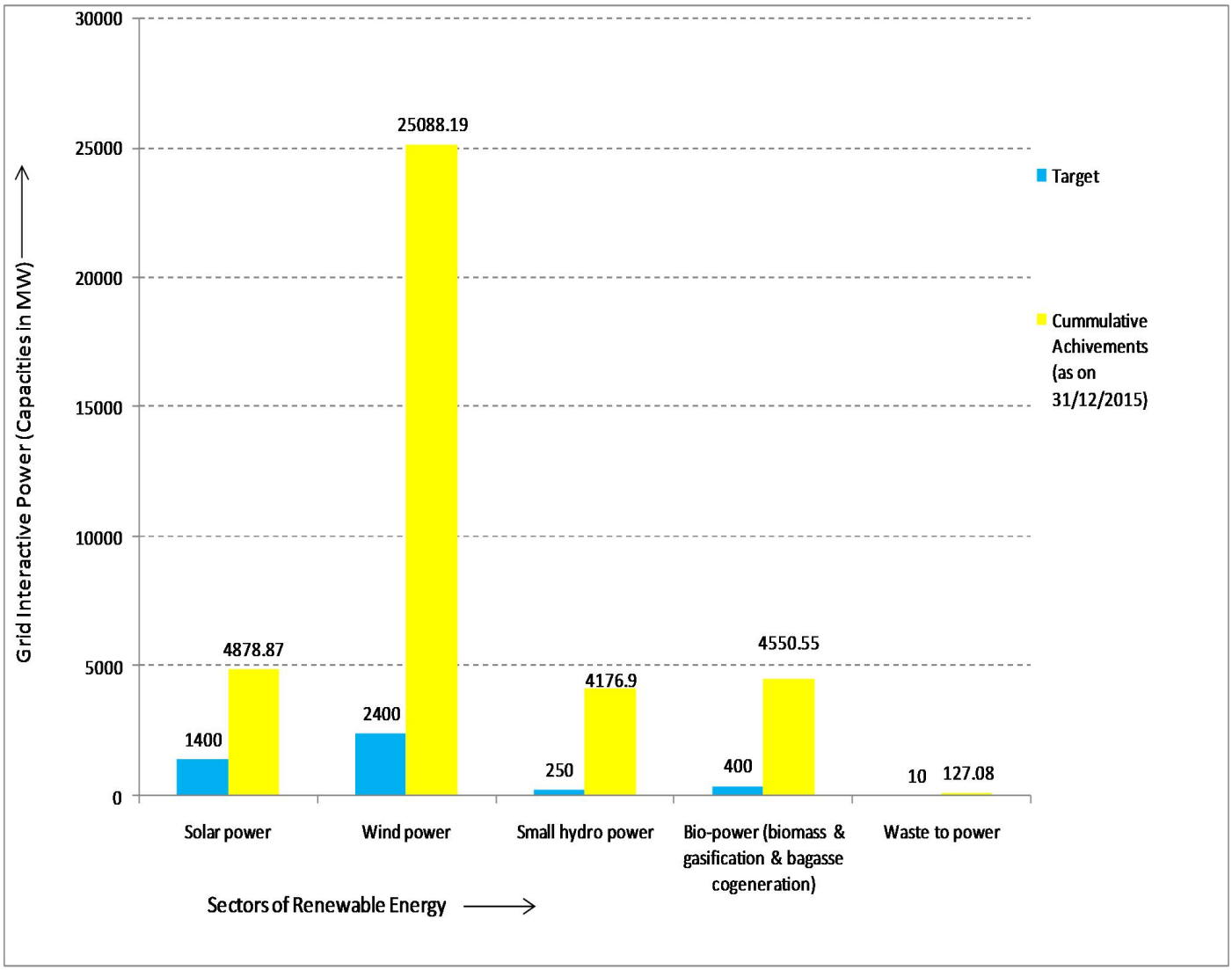

Fig. 1 Bar chart of the Grid interactive power [11]

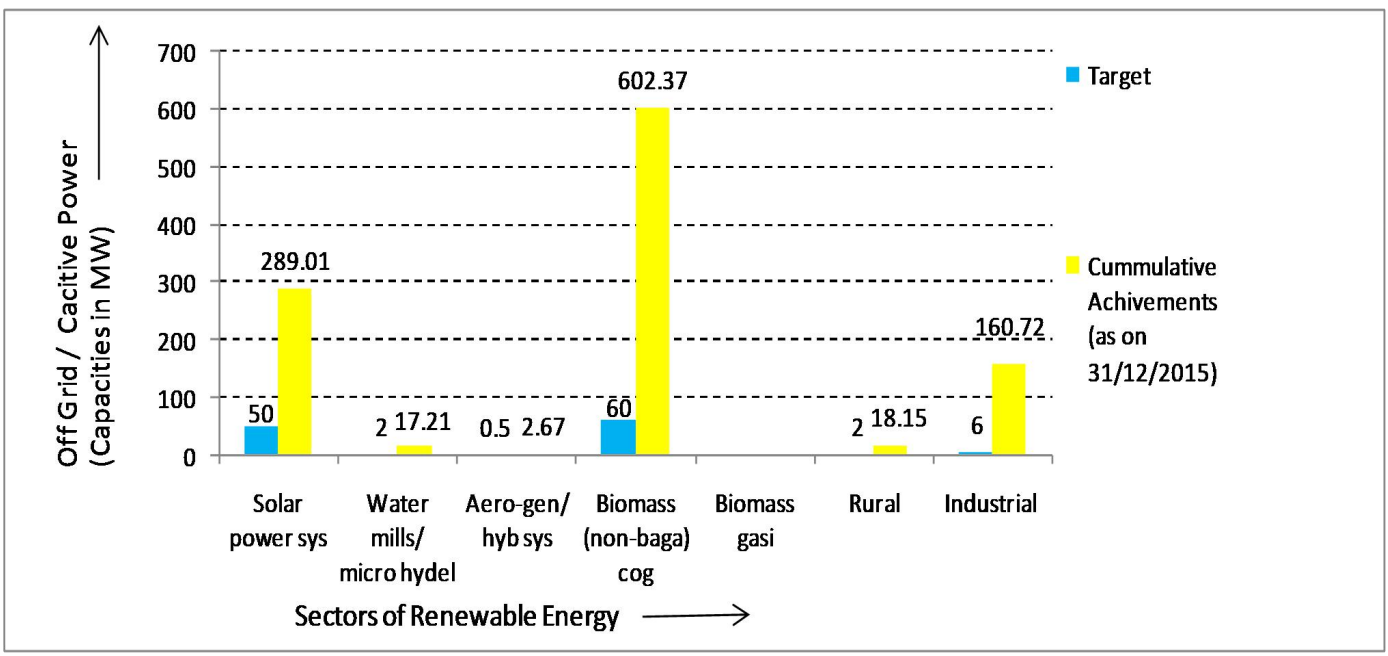

Fig. 2 Bar chart of the Off Grid/Capacitive Power [11]

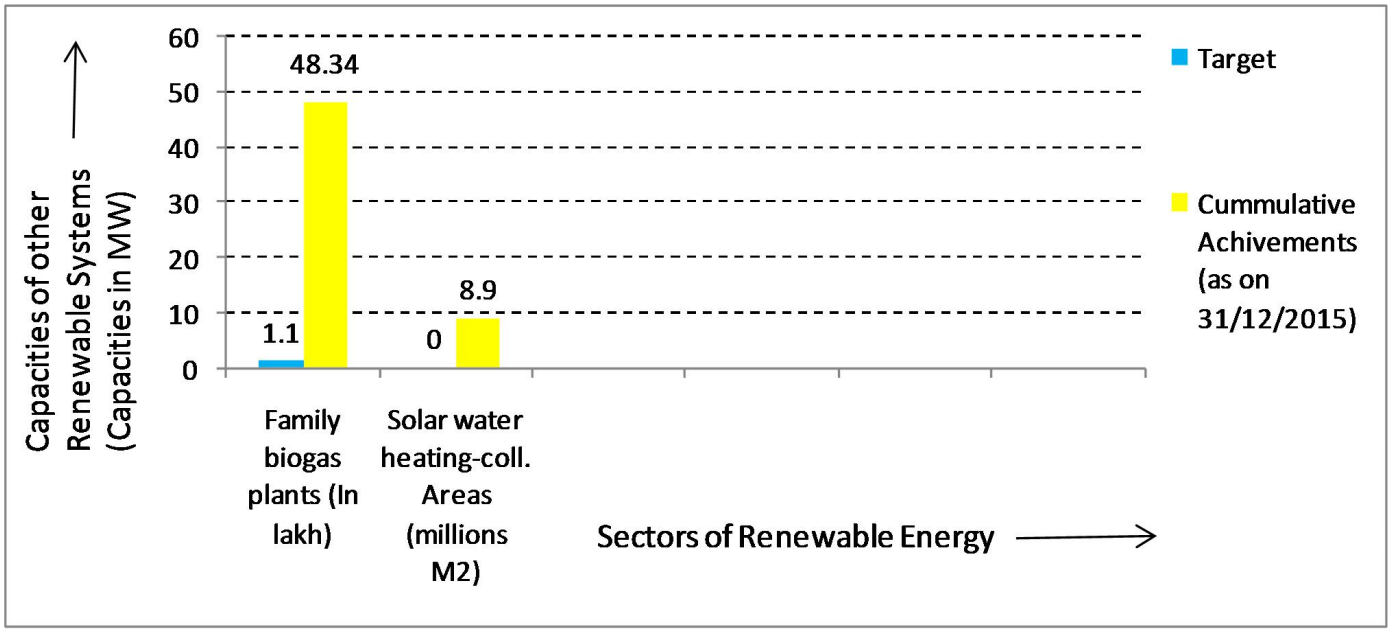

Fig. 3 Bar chart of the Capacities of other Renewable Energy Systems [11]

3. Solar Photovoltaic System: Components and Model

The solar photovoltaic system has a very old history. Alexander Edmond Becquerel discovered the photovoltaic effect (photo-electric effect) in 1839. In 1880's the photovoltaic cells were built for the first time (the material of the cells was selenium). These selenium materials were very costly and less efficient (1-2%). The Bell Laboratories produced a PV cell in 1954 having an efficiency of 4%. A practical application of an array of photovoltaic cell about 1 W was done by US Vanguard space satellite in 1958 [12]. In 1959-60 the efficiency of photovoltaic cells got improved to 14%.

In 1963 and 1976 first silicon photovoltaic modules and first amorphous silicon photovoltaic cells were implemented by Sharp Corporation and RCA Laboratories respectively. In 1992 and 1994 a thin-film photovoltaic cell of Cadmium Telluride (Cd-Te) was implemented having an efficiency of 15.9% by University of South Florida and a solar cell (GI phosphide and GAs) was implanted by The National Renewable Energy Laboratory having efficiency of 30% respectively. In 1999 world's total installed capacity of photovoltaic reached one thousand MW. Many implementations were done in world during 2002 by different organizations regarding the developments and applications [13].

3.1) Solar Photovoltaic panels and arrays

A solar photovoltaic array consists of number of sub-systems. Solar cell is the smallest part of a photovoltaic array, these solar cells are arranged together to make a solar PV module. Many solar PV modules form a solar panel.

These solar panels are designed in an arrangement known as solar PV Array. Solar Modules are connected in series and parallel depending on the desired voltage and current. The series connection of module provides the increase in voltage while the parallel connection provides the increase in current [14]. The following Fig. 4 explains the Stage wise design of solar photovoltaic array from a solar cell [14].

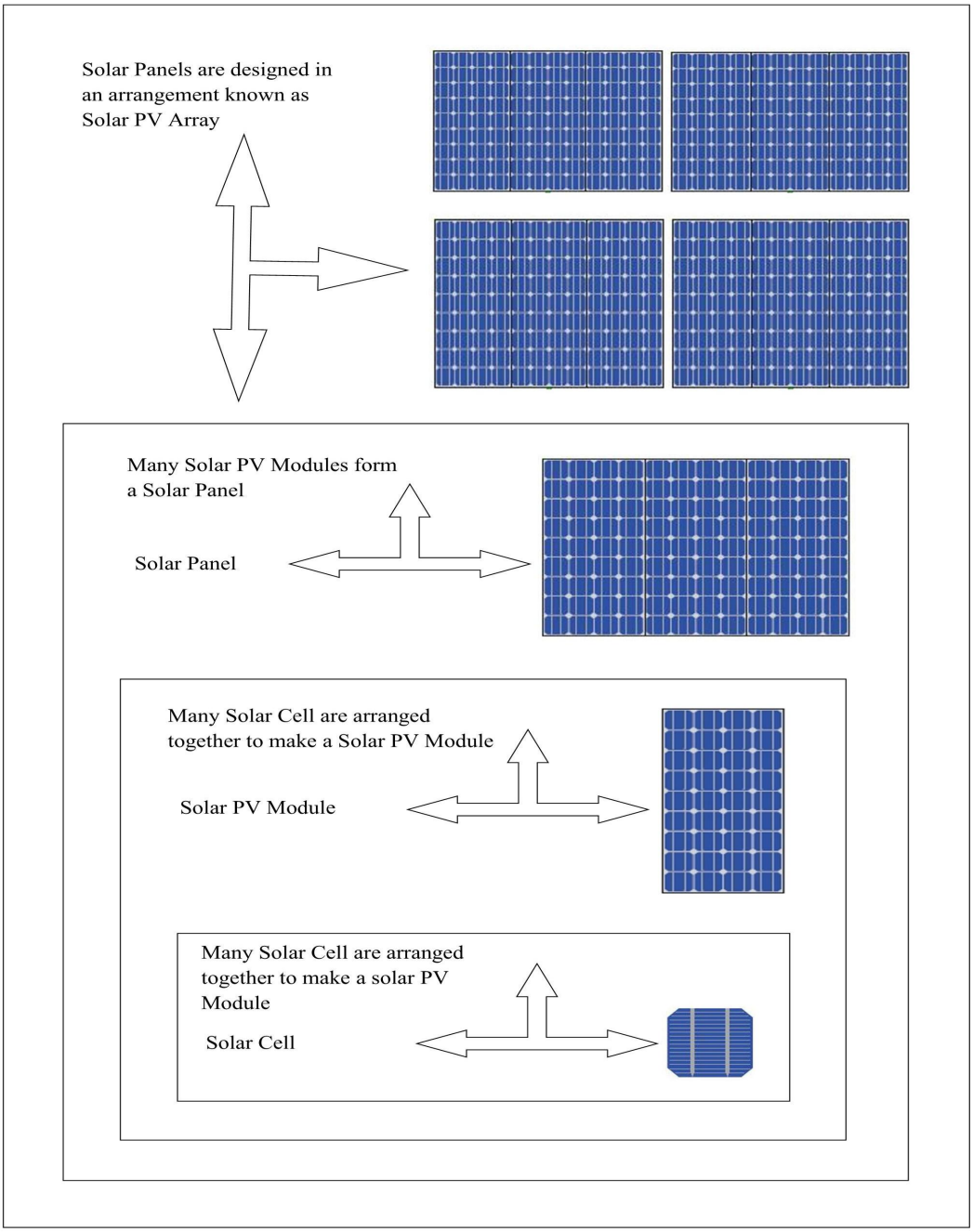
Solar Panels are designed in an arrangement known as Solar PV Array
Many Solar PV Modules form a Solar Panel
Solar Panel
Many Solar Cell are arranged together to make a Solar PV Module
Solar PV Module
Many Solar Cell are arranged together to make a solar PV Module
Solar Cell

Fig. 4 Stage wise design of solar photovoltaic array from a solar cell [14]

The solar photovoltaic system can be of three types:

Grid connected solar PV systems: [14-15]

The grid connected solar PV systems are designed without batteries and are connected to a power grid. A grid connected solar PV system can have the following components:

- PV panels/Array/Modules
- Charge controller
- Inverter

The Charge controller helps to provide efficient and reliable operation of the overall system. Many intelligent methods like fuzzy logic etc are used to control charge controller for effective results [16]. Inverter converts the DC generated by solar panels into AC and Battery stores the extra energy [17].

- **Off grid solar PV systems**:

  The off grid solar PV system has no power grid connected to it, and is designed with PV panels and load only. In off grid solar PV system one more component is added that is storage of electrical power besides the grid connected system components [18].

- **Hybrid system**

  A hybrid system is proposed where conventional PV systems are not suitable due to climate conditions, size of installation, cost and other parameters. It combines solar photovoltaic systems with other electricity generations systems (like wind, diesel etc) for a reliable operation [19-22].

3.2) Applications of Solar PV System

Broadly the applications of Solar PV System can be studied as [23-33]:

- Agriculture: in automatic irrigation system
- Industry: For reliable power supply, Street lights etc
- Telecommunication: Radio and TV relay stations, wireless and remote communications
- Health: Emergency Power supply
- Cooling systems: Air conditioner, Refrigeration
- Ventilating loads
- Domestic and street lighting
- Transportation: solar boat, vehicles, airplanes, ship power.

3.3) Different PV Technologies

There are various types of PV technologies like crystalline silicon (Mono Crystalline type, Poly Crystalline type), Amorphous, CIS etc [33].

The PV technologies are classified into two broad categories:

- **Crystalline silicon type**
- **Thin film type**

The Crystalline Silicon PV cells are divided into Mono-Crystalline and Poly-Crystalline PV Cells. Thin film PV cell consists of Cd Te (Cadmiun Telluride), CIGS (Copper Indium Gallium Selenide), and a-Si (Amorphous Silicon).

The following Fig 5 shows classification of PV technologies. The following Table 5 shows the conversion efficiency of the various PV technologies. The Table 6 below shows the temperature coefficient (%/^{o}c) as performance of the PV module changes with the variation in temperature [34].

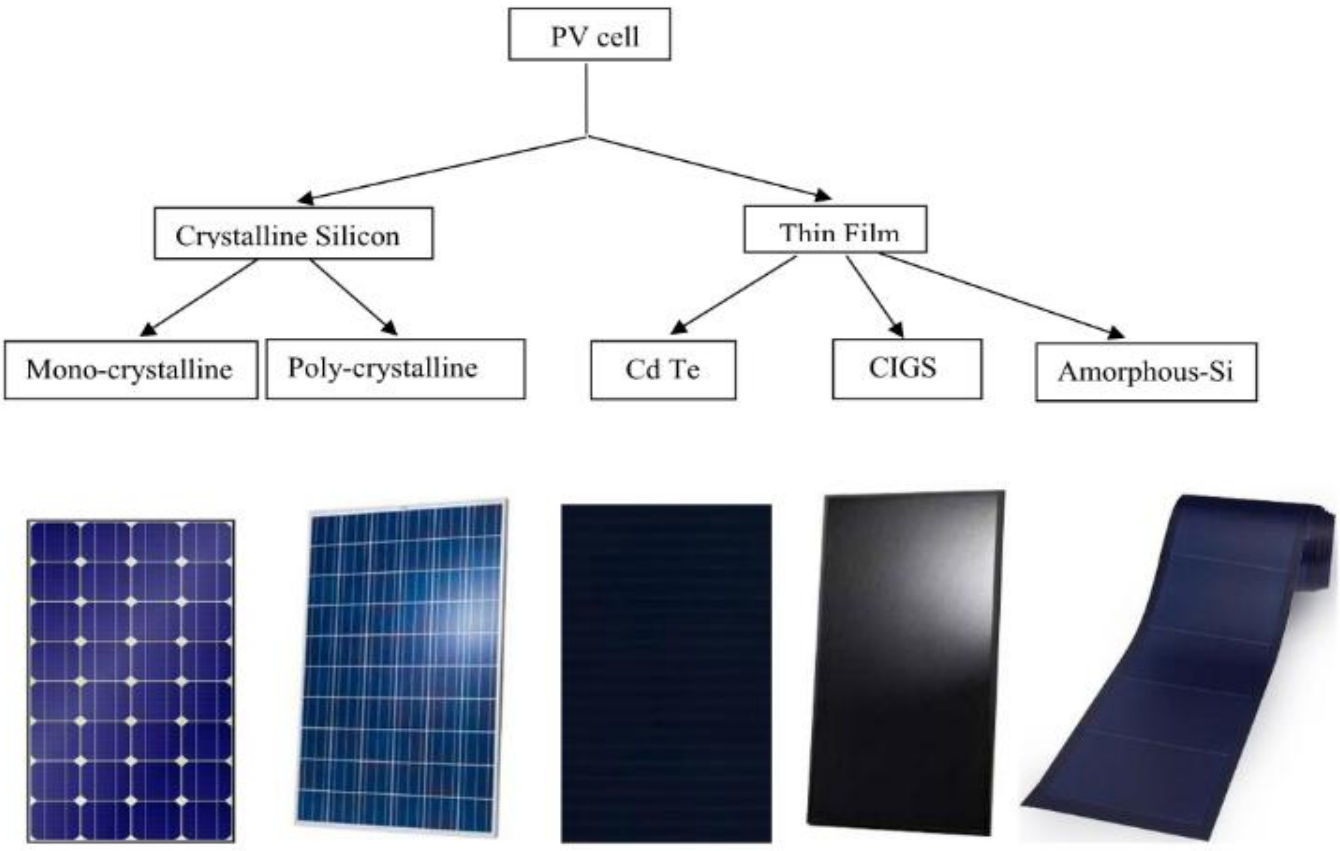

Fig. 5 Shows classification of PV Technologies [34]

Table 5 Conversion Efficiency for different PV Module Technologies [34]

1	Mono-crystalline Silicon		12.5-15%
2	Poly-crystalline Silicon		11-14%
3	Thin film		
	A	Copper Indium Gallium Selenide (CIGS)	10-13%
	B	Cadmium Telluride (CdTe)	9-12%
	C	Amorphous Silicon (a-Si)	5-7%

Table 6 Different PV Technologies with their Temperature Coefficient as (%/^{o}c) [34]

1	Crystalline Silicon		-0.4 to -0.5
2	Thin film		
	A	Copper Indium Gallium Selenide (CIGS)	-0.32 to -0.36
	B	Cadmium Telluride (CdTe)	-0.25
	C	Amorphous Silicon (a-Si)	-0.21

4. Faults in Distributed Solar PV Generation System and Their Classification

4.1) Types of Faults

Mainly the Distributed Solar PV Generation System can be divided into two parts:

- **DC Components and**
- **AC Components.**

In DC side of a PV system the following types of fault can occur:

- **PV Panel/ PV Module faults**: It consists of Earth fault, Bridge fault, Open circuit fault, Mismatch fault.
- **Cable faults**: It also consists of Bridge fault, Open circuit fault and Earth fault.

In AC side of a PV system the fault can be from lightening, Grid failure or faults from outside etc.

The figure 6 illustrates different types of faults in a solar PV system.

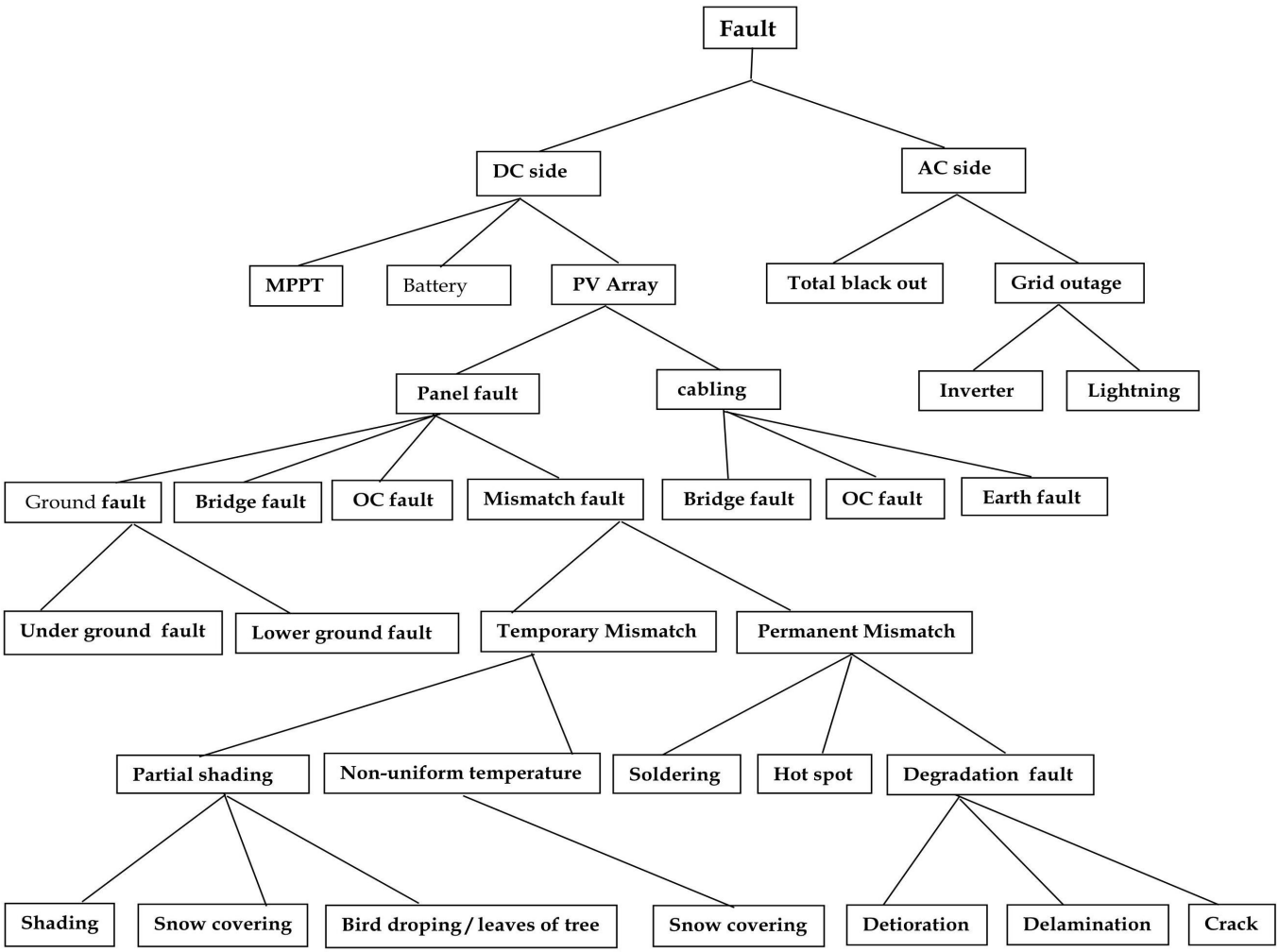

Fig. 6 Showing Different Types of Faults in a Solar PV System [35]

Mostly the mismatch faults occur in PV array causing a serious damage and high power loss to the PV modules. Partial shading, hotspots, soldering, degradation (discoloration, delamination, etc) are few types of temporary and permanent mismatch faults [35]. Solar PV array may also have ground faults, Line-Line fault, Arc fault [36] or failure in either solar panel or inverter [37]. The shadow on a solar panel surface may cause hot spots, which heat the nearby area and results in failure of the panel. To avoid hotspots blocking diodes are used [38].

5. Health Monitoring of Solar PV system

5.1) Need of Health Monitoring

The Health monitoring of solar PV system refers to the stage at which a system is working with satisfactory operation. A system with health monitoring can avoid fault and provide a better output [39]. Monitoring and control of PV system

increases efficiency and provides a reliable operation as the generation of solar PV system is distributed so there is a need to remotely monitor the health condition of PV distributed generation system [40]. The health monitoring has very wide area. In civil Engineering it can be used to monitor the structural health for the bridges which are supported by cables, buildings and other civil structures. The cracks, deterioration and other damages can be determined using sensors & software techniques [41-44]. Whereas in medical field the health monitoring helps to remotely monitor the health condition of patients. It uses different kinds of sensor and wireless techniques and the information related to health monitoring can be easily accessed on mobile phone [45-48]. The wireless network sensors are also used to monitor the environmental factors like pollution, heat etc as well as to locate the deteriorations in the pipelines of water supply if any [49-50]. The combination of electrical and mechanical sensor technologies along with wireless technologies is also used to monitor airport pavement [51].

5.2) Health Monitoring Techniques

Both the software simulation [52] as well as hardware techniques are used for health monitoring [53] to analyze the effects of faults due to environmental effects (dust, changes in temperature and relative humidity etc) [54], shading effects, measuring of the operating voltage, current, plotting of I-V curve etc [55-56]. While hybrid methods with both software and hardware are also used [57-59].

Software Techniques:

The software used to simulate the different types of PV Array and analyze the health conditions for different types of fault (like shading effects, temperature effects etc) is MATLAB/simulink software [60]. The effects of different types of fault like partial shading (temperature effects, effect of using bypass diode) [61], efficiency, characteristics of PV panels in different shading environment (buildings, birds, grass etc) [62-63], mismatch faults can be simulated using the above software [64].

Software Techniques used for intelligent algorithms to automatically monitor the solar PV system are:

i) Fuzzy logic: It has 3 stages Fuzzification, Fuzzy inference system and Defuzzification (output). A fuzzy logic controller is used to control the parameters according to the desired value.

ii) ANN: It works in 3 steps first is collection of data secondly training of data and third is Justification of output.

It performs task quickly and accurately. ANN can be used for the detection of 3 types of faults namely degradation, short circuit and shading.

iii) GA: It can perform a number of solutions simultaneously. It has 3 parameters Selection, crossover and mutation.

iv) Other intelligent systems (ANFIS, combination of ANN and GA etc): Some software tools can be combined together to achieving better results like ANFIS (Adaptive Neuro-fuzzy Inference System), combination of ANN and GA [65-67].

Hardware Techniques:

The Hardware Techniques can monitor the PV system against various faults (like partial shading effects for PV array) [68-69] with a well designed circuit, wirelesses sensor technology etc [70]. Normally by visual inspection the cracks on the panel surface, decay of Anti-Reflection coating, discoloration of glass encapsulate, damage to cell encapsulate interface and back sealing surface, blister, corrosion in cells and in busbar can be detected to get an idea of the health monitored PV system[71].

But when faults are not visible a thermal camera is used. The deposition of soil, snow and bird deposition on PV panel surface increases the overheating of the cell and causes hot spot on the PV panel surface. This hot spot causes degradation of solar panel. The thermal camera helps to detect the effects of deposition, temperature distribution of natural aged panels, discolored cell, cracks and blister by capturing thermographic image [72-73].

There are methods like Liquid crystal thermography [74], Electroluminescence camera [75] and other inspection X-ray, ultrasonic method, eddy current used for hot spot detection [76].

6. Problem Statement

To Design and Development of Better, efficient and reliable health monitoring system for Distributed Solar PV Generation System.

7. Proposed Strategy for the Health Monitoring system of Solar PV Distributed Generation

The mismatch faults are most common as compared to other faults. The sensors and thermo-vision cameras are used for the detection of hotspots, deposition effects, and thermal degradation effects of solar PV panels.

Therefore for the health monitoring of solar PV system the proposed study will deal the following aspects:

i. Study of SPV system and its condition monitoring.

ii. Mathematical modeling and simulation for data generation

iii. Development of health monitoring system and its validation

iv. Analyze the methods applicable for the health monitoring of the SPV system

v. Practical implementation

8. Flow chart of the Proposed Work

The flow chart for the proposed work is given below in the Fig. 7

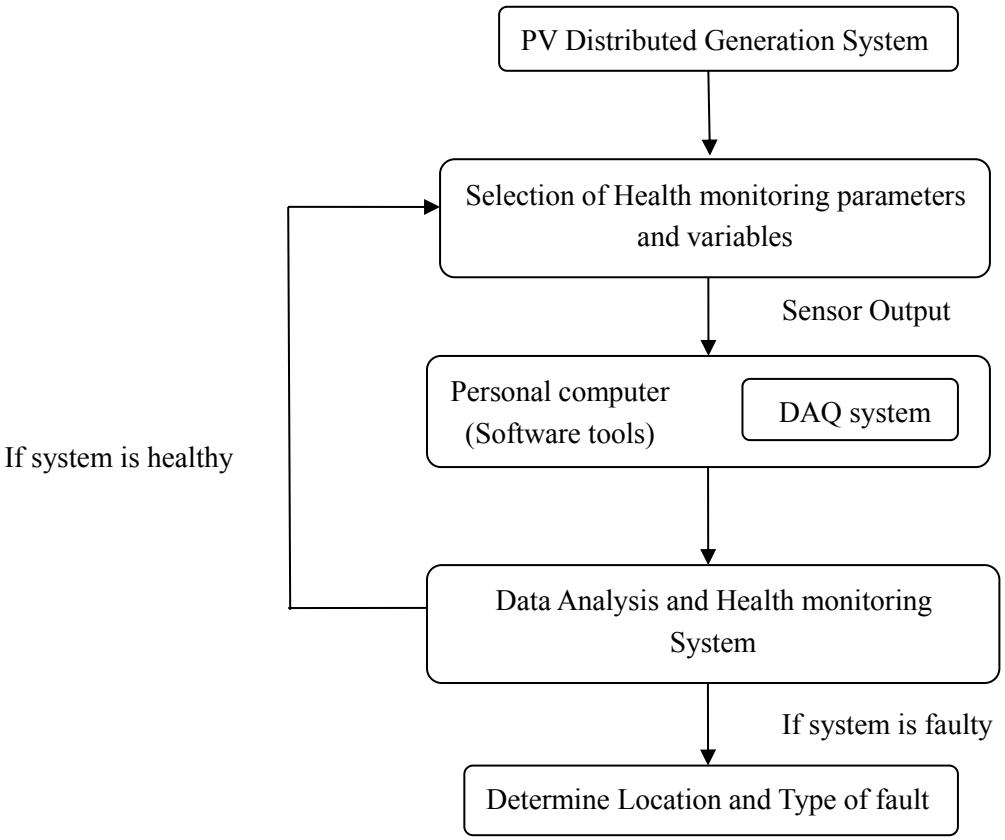
PV Distributed Generation System
Selection of Health monitoring parameters and variables
Sensor Output
Personal computer (Software tools)
DAQ system
If system is healthy
Data Analysis and Health monitoring System
If system is faulty
Determine Location and Type of fault

Fig.7 Flow chart for the proposed strategy

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